Strategy and Tactical Decisions in Fire Suppression based on Wildland Fire Simulations.

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Strategy and Tactical Decisions in Fire Suppression based on Wildland Fire Simulations

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Abstract

The new fire scenario generations, the so called 3rd, 4th and 5th by Castellnou & Miralles (2009), are characterized by involving convective fire behavior and fire environment (3^{rd} generation), fire spreading in Wildland Urban Interface (4^{th} generation) and simultaneous extreme fires called "Megafires" (Castellnou et al. 2011) (5^{th} generation). During these fire events to the take the best decisions in the first burning periods it is critical, to avoid fires to burn all their potential.

The Wildland Fire Analyst (Molina et al, 2010) is a new job position that has an increasing relevant role in many European fire response agencies. This job position tasks includes, studying the local wildland fire behavior and understanding the propagation patterns related to different terrain and weather scenarios. The first attempt was conducted in Catalonia in 1999, establishing this job position (Wildland Fire Analyst) in its Incident Command System. Later on other European regions have proceeded in a like manner. This is the case of other regions of Spain like Gran Canaria, Castilla La Mancha, Aragón, Andalucía to name some of them, and in other countries and European regions as Portugal and Sardinia (Italy).

This new generation of fire specialists and the use of geotechnologies in wildland fires are becoming key tools to provide best support to the Fire Chiefs towards sound Strategy and Tactical Decisions. The new generations of wildland fire simulators try to provide best answers in real time about the expected adverse fire behavior ahead, before the extended attack resources arrive to provide an enlarged support. Integrating the increasing fire observation capabilities (by fire suppression officials) in the wildland fire simulators provides relevant data to real time calibration.As a wildland fire behavior changes are common, simulation calibration and adjustments are instrumental to obtain more reliable simulations and make easier the decision making of firefighters.

This proposed methodology is focused on potential based wildland fire analysis and actual fire suppression operations (Castellnou & Miralles, 2007), and the Wildfire Analyst™ simulator (Ramirez et al., 2010),that includes the strategy and tactic concepts. The objective is to obtain fast and simple simulations to support strategic and tactical decisions in the first steps of the suppression response to ensure a reduction in the wildland fire size potential from the beginning. It simulates the wildland fire in sections, evaluates both the fire potentials and the trigger points (Campbell, 1995; Castellnou et al. 2011) in every section. It designed to be used in real time, to help the Wildland Fire Analyst propose strategy actions and support the Incident Commander (IC) to explain them.

Several examples of the application of the present methodology in fires both in Catalonia and Southern California in 2012 and 2013 will be presented, as both share similar fire scenarios of fast and intense wildland fires, and is in the first steps of these wildland fires where this decision methodology works.

Key words

Wildland fire analysis, wildland fire simulation, Wildland Fire Analyst, strategy, tactics, operations, fire potential, decision making process.

Introduction

Understanding the definition of Large Wildland Fire, LWF, as a fire that is out for the suppression capability in a sustained way in a determined time, we can understand the five wildland fire generations (Castellnou & Miralles 2009):

- First generation (1950s and 1960s): The continuity of fuel over the landscape allows large perimeters in a landscape without firebreaks, so no anchorages. They are surface fires and mainly driven by wind that burn 1000ha to 5000ha. The response is based on local resources, and reinforced with seasonal firefighters. Building water points, firebreaks and linear infrastructures as anchorages, and roads to increase accessibility.
- Second generation (1970s and 1980s): The amount of fuels allows faster fires and spotting. The speed of these fires overruns the holding lines. These fires burns 5.000ha to 10.000ha, burning in a topographic and wind pattern. The response is dense detection and suppression net distribution, to ensure a fast powerful arrival of fire engines and helicopters. Efforts are focused on a forceful direct attack. Water is an ideal tool. Aerial resources increasingly involved.
- Third generation (1990s): These fires are characterized by the increasing fire intensity. Fuel build up allows crown continuity, resulting in active crown fires and convective plumes, out of suppression capability. Each fire offers very few opportunities to control. The changes in the fire behavior are faster than the information can move through the chain of command. They are crown fires spotting burning 10.000ha to 20.000ha. Generally they burn with the presence of a heat wave which supports these high intensity fires. The fire risk models are introduced as a response, to adapt resources availability to the probably of large fires. Fire analysis is identified as a tool to plan in advance and not only react to fire. Improving efficiency by using a broad range of opportunities, widening the suppression techniques: reintroducing fire and manual and mechanical tools, reinforcing aerial attack, improving efficiency with combined tools. Introduction of logistic units and lowering the decision level for a faster response to changes in fire behavior.
- Fourth generation (since 2000): The Wildland Urban Interface (WUI) becomes involved in the forest fire environment. Residential and industrial areas are increasingly affected by wildland fires. These fires can start and be stopped inside the WUI and burn more than 1.000ha. The new landscape situation forces a change from attacking the fires to defending houses and people in a new defensive situation. Fire analysis grows as a tool. Simulators, GPS and mapping are useful to follow resources on time appears.
- Fifth generation (since 2000): Also called Mega-fires. Zones at risk are faced with simultaneous large, fast and extremely intense wildfires. The spread as crown fires involving urban interface zones, mainly during heatwaves. To respond these wildfires are needed new skills, the answer is resources sharing, but new types of knowledge co-operation and exchange information and experience are also needed.

Fire analysis is an important and increasingly tool to manage these LWF the 3rd, 4th and 5th fire generations in episodes. This fires scenarios (3rd, 4th and 5th generations) were common in regions of Europe like Portugal 2003 and 2005, southeast France in 2003 and 2009, northwest Spain in 2003, 2009 and 2012 and Greece in 2000, 2007 and 2009 (Castellnou et al. 2010). The Campbell Prediction System Language, CPSL, (Campbell, 2005) provides a tool to answer, where and when fire behavior will change. Also where and when can implement suppression actions. It helps to act in a proactive way.

The Fire Behavior analyst (FBAN) is a job position who establishes a weather data collection system, develops the required fire behavior predictions based on fire history, fuel, weather and topography information (Firescope, 2012). The Wildland Fire Analyst, WFAN (Molina, et al. 2010) is a fire specialist high trained and experienced, he or she is a merge of the FBAN and some tasks by other IC positions, having the next goals:

- Understanding how fire spreading according the fire types (Castellnou et al. 2010) and the observed past fire behavior to forecast eventual fire behavior changes, in both time and space and to identify the critical/trigger points well as those opportunities (explicitly on the topography) where the fire front flames are under the suppression capability of wildland firefighters in direct attack.

- Helping the incident commander to decide the action plan, defining the strategy and tactics based on analysis of the fire potential, identifying the spatial-temporal window (actuation window) for every suppression operation. This last item means finding safe places on the terrain to locate resources and decide when to implement these operations.
- Guiding the fire operations, taking part on them, determining the most appropriate pattern to contain the fire or slow down propagation towards firefighters working in the flanks.
- Deciding in the first steps, prior to extended attack, how to limit the fire potential. In the Mediterranean ecosystems wildland fires can burn more than 1000ha (several catchments) in 4-5 hours, during heat waves (hotter hours in the day) or strong winds episodes (La Jonquera 2012, Mountain Fire 2013, Maçanet de la Selva 2003, etc.). So, It is important decide from the very beginning because, identifying the key trigger points and doing efficient maneuvers with a short actuation window it is possible cut the main fire paths.

Since 1999 the WFAN has been a job position in Catalonia Fire Service. There are different training levels to complete WFAN curricula (Castellnou et al. 2012):

- Analysis I: Basic knowledge of wildfire analysis. To plan and communicate the interpretation between the fire and the vegetation.
- Analysis II: To apply the wildfire analysis knowledge. To plan tactics operations in the fire suppression.
- Analysis III: To apply the wildfire analysis knowledge. To interpret and communicate the information observed in the fire line. Monitoring and assessment tasks of fire behavior in the assigned sector.
- Analysis IV: To plan tactics operations in the fire suppression in a sector of a LWF.
- Analysis V: To plan tactics operations in the fire suppression in LWF.
- Analysis VI: Strategic analysis. To be able to make the strategy decision in LWF.

Currently there are some new technologies in wildland fires issues which have different applications such as communications and mobile, geospatial support, real time fireline, situational awareness and relevant analysis training (Ramirez, 2013). There is an increasing need for spatial wildland fire analysis in support of incident management, fuel treatment planning, wildland urban interface assessment and land management plan development (Stratton, 2006). Is in this field, spatial wildland fire analysis, where the operational simulators, like Wildfire Analyst (Ramirez & Monedero, 2009), have and important role. A model is a simplification or approximation of the reality and hence will not reflex all of reality (Burnham & Anderson, 1998), so using the best inputs you can add the output, the reflex of the reality, will be better. In 1979 Geoerge Box said: “All models are wrong, but some are useful”, so it is the task of the modeler to select the appropriate model, produce usable output and interpret model findings given model assumptions and limitations (Stratton, 2006). The obtained output has to be usable in you actuation area related with the fuels model, adapting the characteristics, changing the phenologic scenario of the 13 models (Rothermel, 1972) or the 40 models (Scott & Burgan, 2005) or just creating one from them. The output also has to be adapted at the fire types, elaborated from the study of synoptic situations and perimeters of historic fires, and analyzing the interaction of the weather with the relief (Castellnou et al. 2010).

In the management of LWF operational simulators matters because they provide a quantitative analysis to the WFAN which lets help in the decision process. They are to support the decisions; however, it is not up to them to take the decision. To be useful during the suppression operations have to perform calculations on real time. Consequently, the IC will be better off to take strategic and tactical decisions, so IC will be more efficient managing this LWF and the firefighter’s safety be adequate.

Wildfire Analyst™ is a last generation operational simulator, as analyzed by Simons (2012) against older tools. It provides very fast results of fire perimeter, intensity, rate of spread and flame length adjusting at real time the obtained simulations with actual observation points along the spreading wildland fire. The tool provides a measurement of the error between the observed Vs the predicted results and which are the adjustment factors to the Rothermel’s rate of spread for every fuel to minimize the error. These adjustments can be used during the fire is spreading to automatically calibrate the model and obtaining more realistic simulations. Wildfire Analyst™ allows this in an easy way and it makes it good for use in the fireline.

In the old days, we use to work with operational priorities, thinking from fire service perspective on what can we do. Therefore we were dealing, mainly at tactics and maneuvers. Introducing strategy we can influence and drive tactics and operations from the very beginning and include other actors (owners, wildlife, air quality, tourism etc…) in our decision making of what part of potential area to be burned we have to focus. A wildland fire produces uncertainty, it is surely a problem. Having strategy and tactics we know what we do, when we do it, where we do it and why we do it; therefore the uncertainty decrease. However, as the fire grows the uncertainty increases too. It is necessary to think in advance of the fire spread. We need to be proactive.

This way of thinking is in use since 1999 in GRAF (Catalonia Fire Service), reaching its mature level in the fire seasons 2012 and 2013 (Prats de Rei Fire 2012, Pinell de Brai Fire 2012, La Jonquera Fire 2012, Vallirana Fire 2013, Aiguamurcia Fire 2013, Tivissa Fire 2013, Vilopriu Fire 2013, etc). More examples can be found in Lo Forestalillo webpage: http://blocs.gencat.cat/blocs/AppPHP/loforestalillo/.

Objectives

In the present work there are the following objectives:

- Development of an operative methodology of wildfire simulation with the software Wildfire Analyst based in expert criteria assessment, to support strategic and tactical decisions, understanding the concepts and uses them like GRAF Wildland Fire Analysts.
- Clarify the concepts of fire potentials, strategy, tactics and maneuvers in wildland fires and establish their interaction in wildfire management.
- Test the Methodology in different territories, in this case in Catalonia and South of California, as they share a similar wildfire regime.
- Show to the community the potential of geotechnologies in wildland fires applied in operations, providing a real time outputs and valid data to help in the decision process.

Materials and Methodology

Strategic wildfire analysis

To understand the proposed methodology is necessary to explain the next concepts about strategic wildfire analysis.

Fire potentials areas

They are defined as homogenous zones where the fire has a similar behavior. The principal criterion to draw them is to identify the trigger or critical points and from them we can draw the potentials. These critical points can be predetermined by geomorphometric analysis (Ramirez & Marqués, 2013). The size of the fire potential areas (or polygons) will be function of the expected fire behavior, taking in account the behavior of the past days fires. The planned actions of the strategy will decide which polygons burn and which do not burn. Depending on the pattern of spread we will identify different fire potential areas so there some differences between topographic, wind-driven and convective fires. Topographic pattern follow the slopes with the steepest gradient and highest insolation daytime, they burn basins and slopes. Their critical points are ravines and intersections of ravines so their potentials are watersheds, generally. In the wind-driven fires the wind interacts with the relief following the ridge line in parallel ridges and in perpendicular the fire is spread by turbulence of the wind. They have the trigger points at the beginning of the ridges and their joins, so the potentials of wind-driven fires are ridges. A convection fire is one that is spread mainly by the convection plume. Heat is carried in the form of hot air and this dries out the vegetation, which is then susceptible to ignition by hot brands of burning embers that are carried within the fire plume (Quilez, 2013). The fire spreads reading the macro-topography and is able to throw spot fires in the next watershed, burning large topographic basins. The wind in convective fires increases the spotting distance creating new ignition points outside of the influence zone of the convective column and accelerating the general spread of the fire (Castellnou et al. 2011). Then, to develop the fire potentials for convective fires it is important change the scale, and identify larger watersheds and larger ridges. The next scheme shows clearly the process to develop the potentials in function of the fire pattern. In the extremes there wind-driven and convective patterns and in the center topography pattern. Without wind the fire is topographic, but with a high fuel load and availability can burn following a convective pattern. The coastal topographic fires (Castellnou et al. 2011) follow the topography and the sea breeze, in function of the strength of it the fire pattern will vary between topographic and wind-driven.

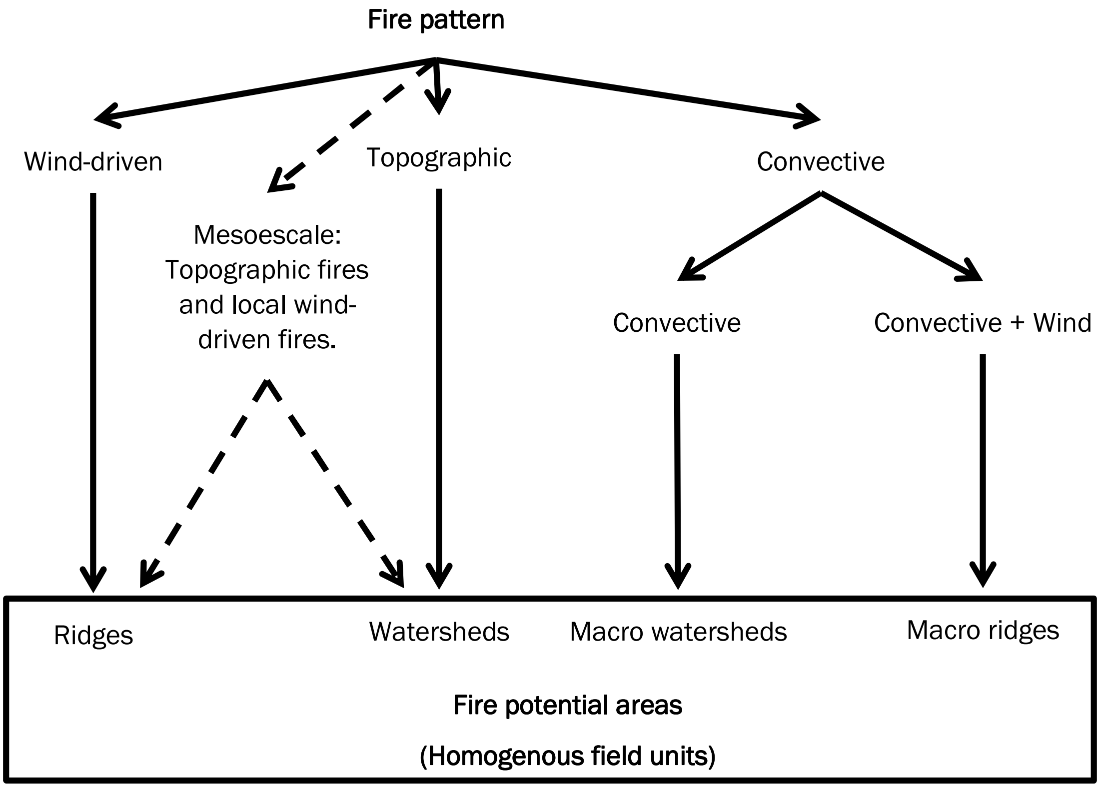

Figure 1 Scheme to develop fire potentials.

Strategy

It is defined as a <u>THE SECUENCE OF ACTIONS WE CAN DO TO REDUCE THE FIRE POTENTIAL AND WHY WE DO THESE ACTIONS</u> to an accepted eventual fire size taking into account its original fire potential area. It is matter of addressing realistic options and feasible actions but always thinking on the big picture. This sequence of actions will allow where and when (tactics) and which tool (maneuvers) we will use to suppress, hold or contain the fire.

The strategy goal is to reduce the fire potential size of a given fire. Our strategy is based on the fire potential analysis. To work on strategic decisions we need make sure all we propose can be done in efficient way in terms of resources used, and always we plan it thinking with safety. So we don't want and tolerate a waste of resources trying to achieve unrealistic operations and we cannot implement unsafe operations either.

We always need to have a B plan and if possible a C plan. Having those will make sure that in case of failure we have resources in B plan to keep the situation under our initiative.

Having a strategy means that we would decide in a proactive way, in advance of fire front movement. We cannot react to what fire is doing and lose the initiative and the leadership. If we lose the initiative we become defensive, not aggressive (proactive). And under a defensive planning we don't decide want we do next, fire itself is dictating us what we would do next and we just do so.

A strategy is not an operational plan, it's planning to direct our operations thinking in achieving realistic goals and make sure fire is not burning all potential in a fixed temporary frame doing that we have options to choose. So a strategy is the outcome of making decision taking into account what can be at risk. The strategy is the actions we can do to make sure the final burnt area is not affecting the values we decided to protect and burned those areas and values we decided were not possible to protect.

The decisions process involves basically answering these three questions (Castellnou & Miralles, 2013):

- **What does the wildland fire want to do?** Pattern of spread according synoptic weather and fuel conditions. Basically axis of direction and all burnable surface that is in its path.
- **What can the wildland fire really do?** Exact and adjusted fire behavior that will tell us main fire paths. It is the interaction on the terrain between the real axis of the fire and the fuel distribution. It says what surface in which time frame and what values.
- **What can we do to avoid this?** Chances we have to plan actions to stop the main fire paths and be able to cut the big potential in pieces. Those pieces are the chunks or polygons of potential. Our strategy will be to decide which ones can be avoided and which ones not.

With those 3 answers and the potentials analysis, we can elaborate a strategy. It will be represented by priorities. Basically we pretend to cut a chunk of potential with every action we take from the beginning. We don't want to waste time and resources trying operations without a clear knowledge about the effects of our action over the fire potential neither want to try unsafe offensive operations or unsafe defensive operations that will attract endless resources and be a distraction of important trigger points.

Tactic

It is defined as a WHERE and WHEN we OPERATE. How we implement the techniques and resources to carry on the strategy. We have to introduce here the concept "actuation window" (where and when we have to apply some techniques). So tactics are defined as operational actions where we will implement the techniques in an opportunity in a determined place and time.

This combination of operations in different areas (flank, head) and the moment to do it is what we say tactic.

Maneuver

It is the technique against the flames. It is an operation in the fire line. Examples: hand line, hose line, backfire, air attack, etc.

The relationship among strategy, tactics and maneuvers is hierarchical. The sequence of actions proposed in the strategy has to be executed in a given order and precise timing when applying a determinate maneuver.

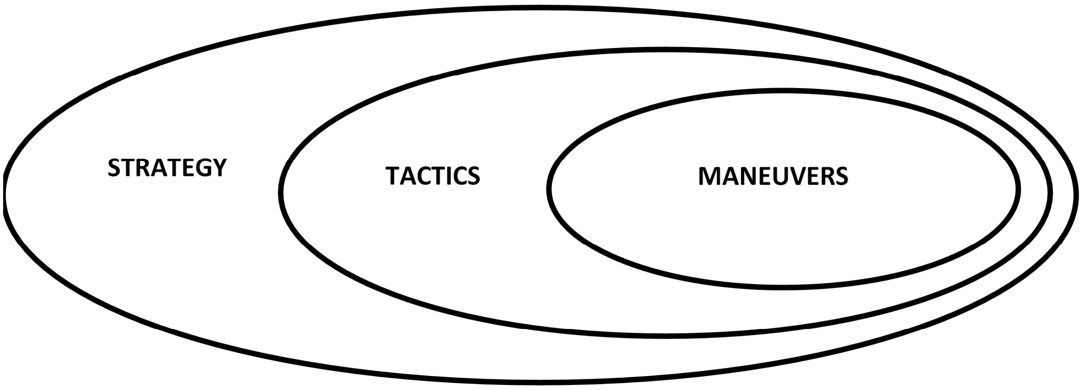

Figure 2 Strategy involves tactics and tactics involves operations

Integration of strategic analysis and operational simulation

To simulate any wildland fire is a need for some inputs to get a reliable simulation. These inputs are: the digital elevation model (DEM), the map of fuel models, the crown cover map, the ignition point, an hour by hour weather file (temperature, relative humidity, wind direction and wind module) and a fuel moisture file (dead and live fuel). Once we have all these inputs we run a wildland fire simulation.

The objective of this methodology is to create an easy and fast way to use the simulator to obtain simulations to support strategic and tactical decisions, it's important to take them in the first hours of the fire, in fast wildfires, so we need to have a clear idea what we do, when we do, where we do and why we do, for this way we will be proactive, we will decide in advance the fire.

It is based on identify homogenous meteorological blocs, called “Stages”, and make a simulation when you identify a change of these, so you have to make a simulation when you have a new meteorological block. The idea is simulate sequentially, stage by stage, with the purpose to readjust the simulation in every stage and perfecting it. The goal is cut the entire simulation with the principal movements of the fire, readjusting every simulation and focusing in the important critical points, though the others parts of the fire spread a little bit. Doing this way is a kind of emulating what fire operational people do in his mind calculations, thinking step by step. The set of simulations will not coincide if we simulate of standard way, but the Methodology works better to take strategic and tactical decisions. It is not necessary get very exact and detailed simulations, it would increase the calculation time of the simulator and with less detailed simulations the calculation time would decrease and we can take decisions faster. The simulations are free spread without suppression.

In the first stage you put an ignition point and run the simulation. In the next stages you put an ignition line where you forecast the growth of the fire. It is important identify the interaction between the wind and the terrain (e.g. lee winds),is the macrotopogrpahy in its interaction with synoptic situations associated to LWF, is the primary factor which controls the fire spreading in complex terrains (Taylor & Skinner, 2003; Expósito & Cordero, 2004; Iniguez et al. 2008). We simulate by sections

In the next figure you can see explicitly the sense and the bases of the methodology.

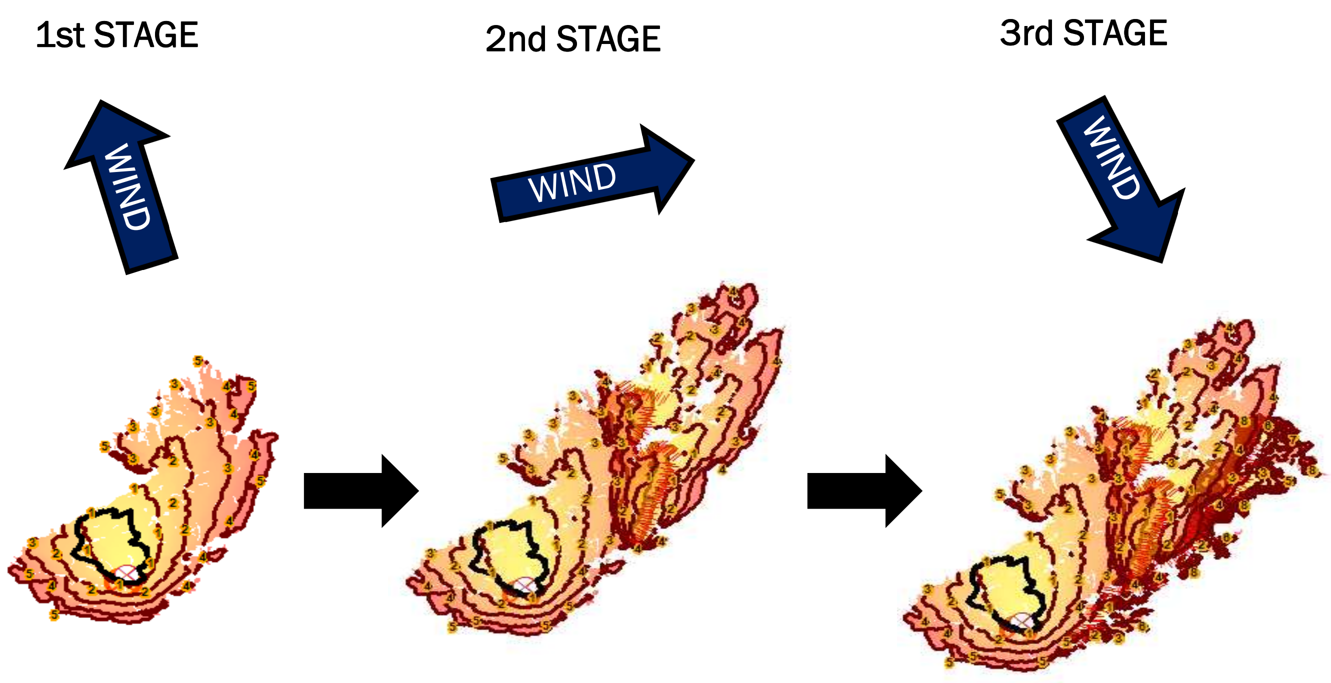

Figure 3 Methodology bases

The previous picture shows an easy and graphic example representing the roots and the application of the methodology. There are three stages. In the first one there is a southeast wind; that means that the fire grows in that direction, so it would grow the first simulation. In the second stage the wind blows westwards, then the right flank will open; it would be the second simulation lighting a fire line in this flank. Finally, in the third stage a northwards wind, so the southern part of the perimeter will grow; it would be the third simulation lighting a fire line in the cue.

To obtain the simulations we have to use the next Wildfire Analyst™ inputs:

1- Weather: We use constant weather because is faster than a weather scenario that use a heavy file with all the weather conditions hour by hour. What we look is for a short term run. With connectivity, direct RAWS or National Weather Service (NWS) predictions can be downloaded in seconds to be used.
2- Fuel: layer of the area. Typically 20 to 30 m/pixel, it can be the 13 models (Rothermel, 1972) or the extended 40 models (Scott & Burgan 2005).
3- Digital Elevation Model: layer of the area. Typically 20 to 30 m/pixel.
4- Fuel Moisture: Fixed valor for the day. It can be calculated from weather data with the Nelson method.
5- Start date: Time and date of the simulation.
6- Number of hours: It depends of the stage duration and when the fire starts.
7- Simulation dimensions: 20 m (60ft) pixel size.
8- Ignition point.

These inputs have to use in every simulation so it means it has to use in every stage.

We use different Wildfire Analyst simulation modes:

- **PROBABILISTIC MODE:** It's used to make strategic simulations. With this mode we get simulations that give us the percentage of the fire burn some area. So, we'll know the potentials affected by the fire in a determined time.
  In the probabilistic mode we have to enter some variables (number of simulations, variation of wind direction, variation of wind module and variation of fuel humidity). These variations will be determined by the WFA. The output of this mode is represented in a color map, differencing the probabilities. The WFA can decide the probability limit (I.e. 40%-100%).
- **PROPAGATION MODE:** It's used to identify the arrival time of the fire in a trigger/critical point. When we get this simulation, we'll know the time, the "actuation window", we have to avoid the fire arrive in the critical point. Knowing this time and the efficiency of our crews we can distribute and prioritize the strategic actions, so we can elaborate tactics.
- **ADJUST MODE:** Used to calibrate the base line simulation with the observed fire behavior. It will calculate and adjusted Rate of Spread (ROS) for every fuel in the current fire, which will be used in the next simulations.
- **EVACUATION MODE:** It is an inverse simulation that calculates the fireshed around an area, that is, the time the fire to reach to that area. It is used to corroborate the arrival time achieved from the propagation mode simulation. It is also used to get the tactics.

  These modes allow working with the simulator in real fires, to obtain operational answers. It is the big difference between the other existing simulators.
  The next picture shows the difference between the propagation mode and the evacuation mode; both are used to get tactical simulations.

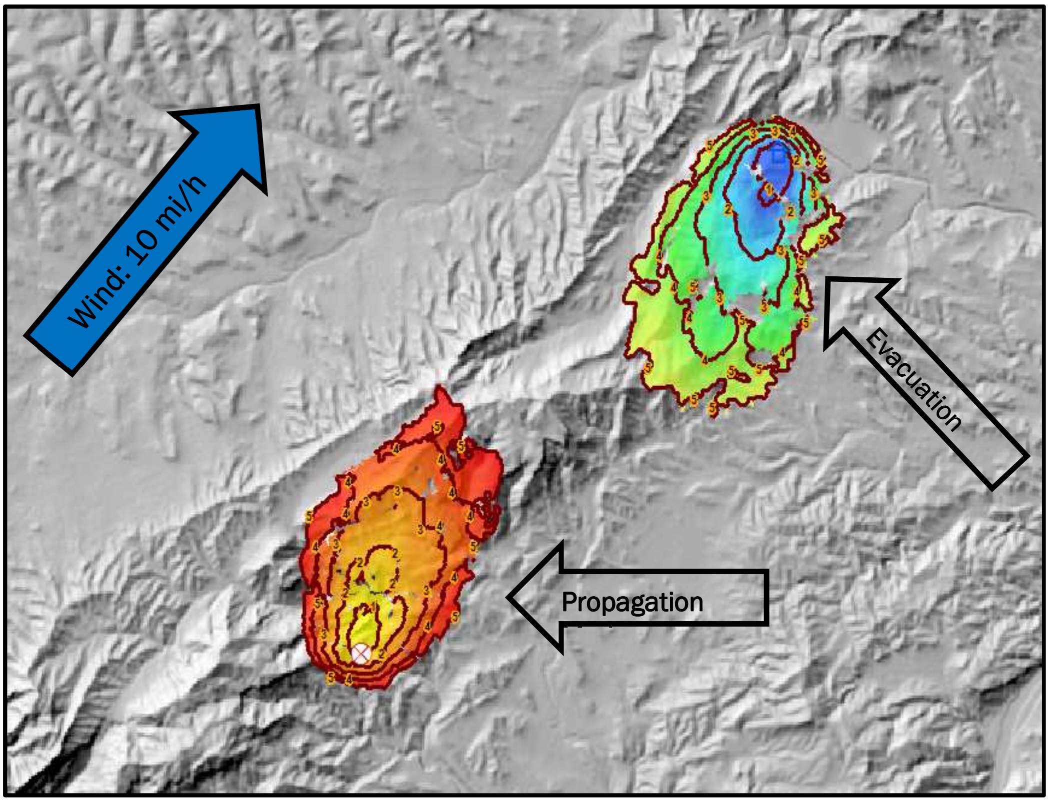

Figure 4 Propagation and Evacuation modes results

Using these four modes, the uncertainty decrease. We get a quantitative analysis, because we get the affected fire potentials areas and the fire arrival time at the critical points (I.e. Wildfire Analyst™ simulator provides us probabilities and fire arrival time.

Proposed Workflow

After applying the inputs outlined before, it has been possible develop the next work-flow, which shows step by step how to apply the methodology. The different colors are similar at the colors of the Wildfire Analyst™ buttons. In blue color we can see the needed inputs, general inputs and the inputs for the probabilistic mode. In green we can see the different used modes, in orange the middle outputs and in red the final outputs. Please, note that this workflow has to be applied in every simulation, in every stage, forecasting the part of the fire will spread. To implement this methodology an expertise is needed as a fine quality control, checking the inputs, adding correct control points and understanding the outputs. Then the simulator will provide adequate and robust outputs.

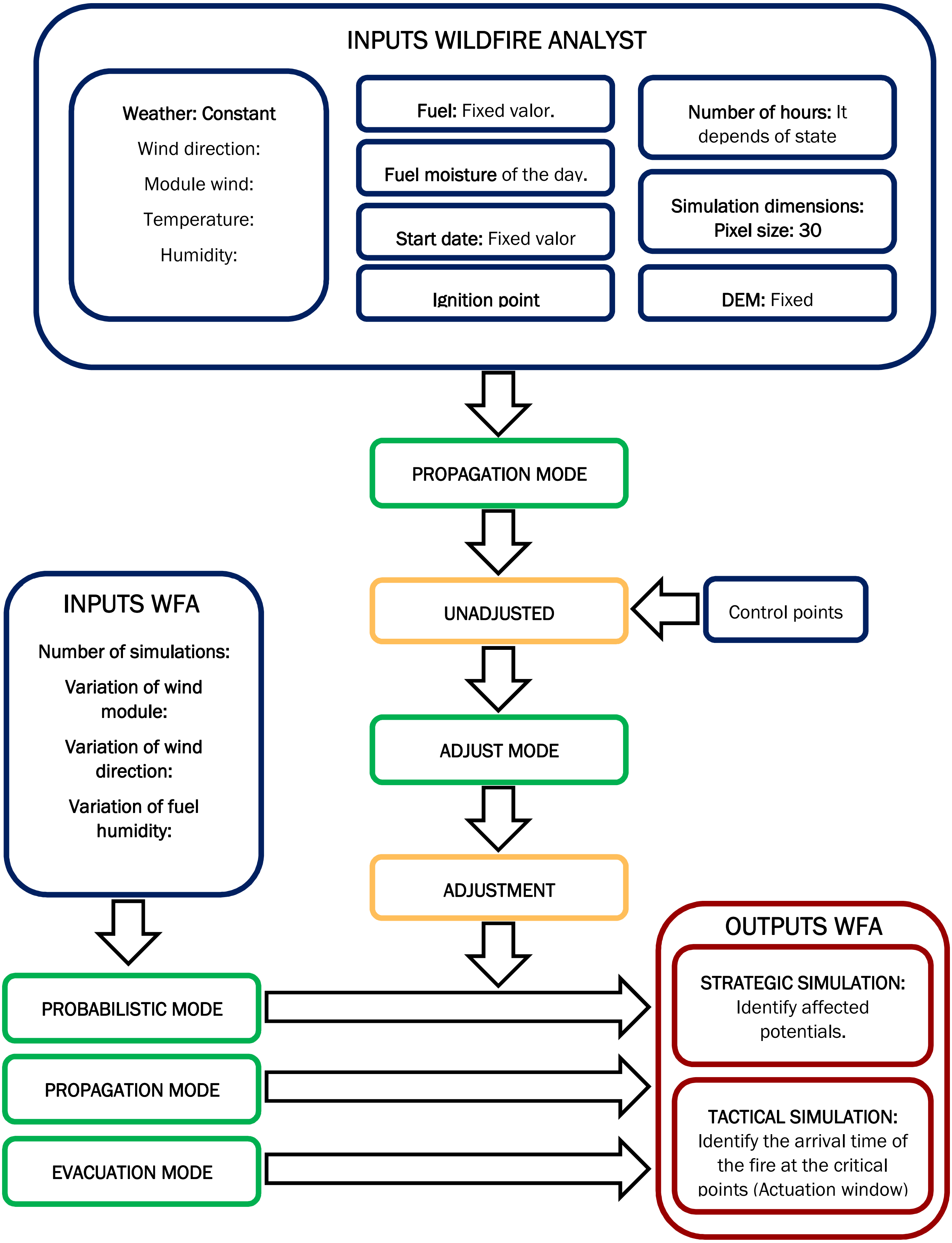

Figure 5 Methodology workflow

Results and Discussion

During the last fire season this methodology has been applied in diverse wildland fires in Catalonia, and some wildland fires from the Southern California (Chariot Fire 2013, Deluz Fire 2013, Silver Fire 2013 and Mountain Fire 2013). Next, you can see one example from Catalonia and another from California.

Pinell de Brai Fire 15/06/2012

This is a wildfire located in Southern Catalonia; it was driven by the sea breeze and the topography. It burned 140 ha in “Serra de Cavalls”. It started at 15:00, when the wind was from S-SE about 25 km/h speed. This breeze varies from the east to the southwest, so we can predict the movement of the fire. It was located in the bottom of a canyon.

As a topographic fire, the critical points are ravines and the join of ravines. Therefore, we have to control fire before those critical points to avoid new fire potential areas. The most important critical point is the entrance at potential number 5, a huge area with heavy fuels with little road access. This fire spreads by runs rear (bottom) towards head (ridge top). Therefore, it is necessary to start to work from rear (bottom) towards the head (ridge top) to reduce the new runs and work with safety to the firefighters.

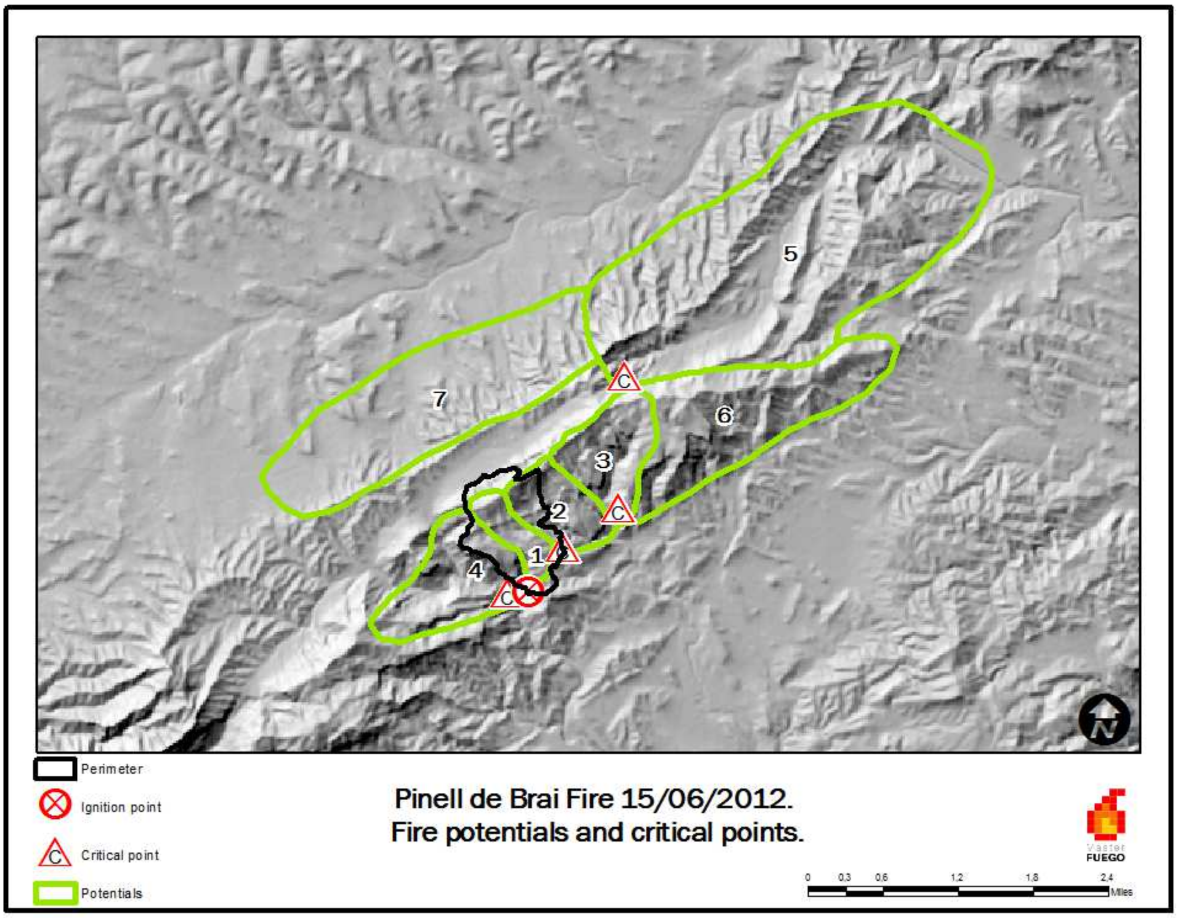

Figure 6 Pinell de Brai Fire 15/06/2012. Fire potentials and critical points.

The potentials sequence is the next:

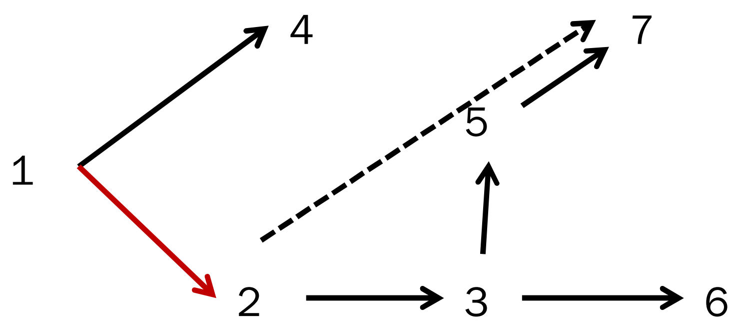

Figure 7 Potential sequence of Pinell de Brai Fire

This scheme (figure 7) shows a dashed line to represent the pass of the fire from fire potential area 2 to fire potential area 7 by flying embers. The red arrow shows what the fire actually did burning fire potential area 1 and 2. The first action done was stop the pass towards fire potential area 4, then avoiding the pass from fire potential area 2 to 5 and 7 and, finally, cut off the pass to fire potential area 3, where it was stopped.

3 questions to be addressed:

- **What does the wildland fire want to do?** It wants to burn all watersheds of the ridge.
- **What can the wildand fire do?** It can burn one watershed and burn the others after flanking downhill. After 2nd and 3rd it can cross the ridge and get to a northern one with bigger potential.
- **What can we do to avoid this?** Attack fire from the rear to the head, reducing the potential of news runs since we will be affecting the flanking speed and gaining time for operations. (1st priority)
  We also can focus resource to avoid passing from fire potential area 2 and 3 to fire potential area 5.

After the sequence potentials and the 3 questions, we have the strategy prioritized:

Strategy

1- To cut the left flank to avoid the entrance to the fire potential area 4, a remote zone without accessibilities. To contain the fire in the northeast side of the road.
2- To progress for the right flank to avoid the new fire runs and avoid the arrival of it at the critical point, so it is the entrance to the fire potential area 5 and the following fire potential areas.
3- To control the flying embers fallen in the other side of the ridge (fire head). There are zones with no fuel, but we have to control embers.
4- Try to contain the fire in the potentials 1, 2 and 3.

To apply the methodology we have to define the stages from the weather of the day, they are the next:

Table 1 Stages resume.

Stage	Temperature (ºC)	Relative humidity (%)	Wind speed (km/h)	Wind direction (º)
1	30	30	25	S-SE
2	25	40	25	SW
3	20	50	8	NW

In strategic simulations, we use the probabilistic mode, as referred above. In order to simulate in this mode, we use the following inputs:

- Number of simulations: 100
- Variation of wind direction: 30º
- Variation of wind speed: 20 km/h
- Variation of fuel moisture content: 3%

The limit is fixed at 60% of burned probability (I.e. we guess the 60% of the simulations of the probabilistic mode affects determined fire potential areas).

Strategic simulations

Probabilistic mode

1st Stage

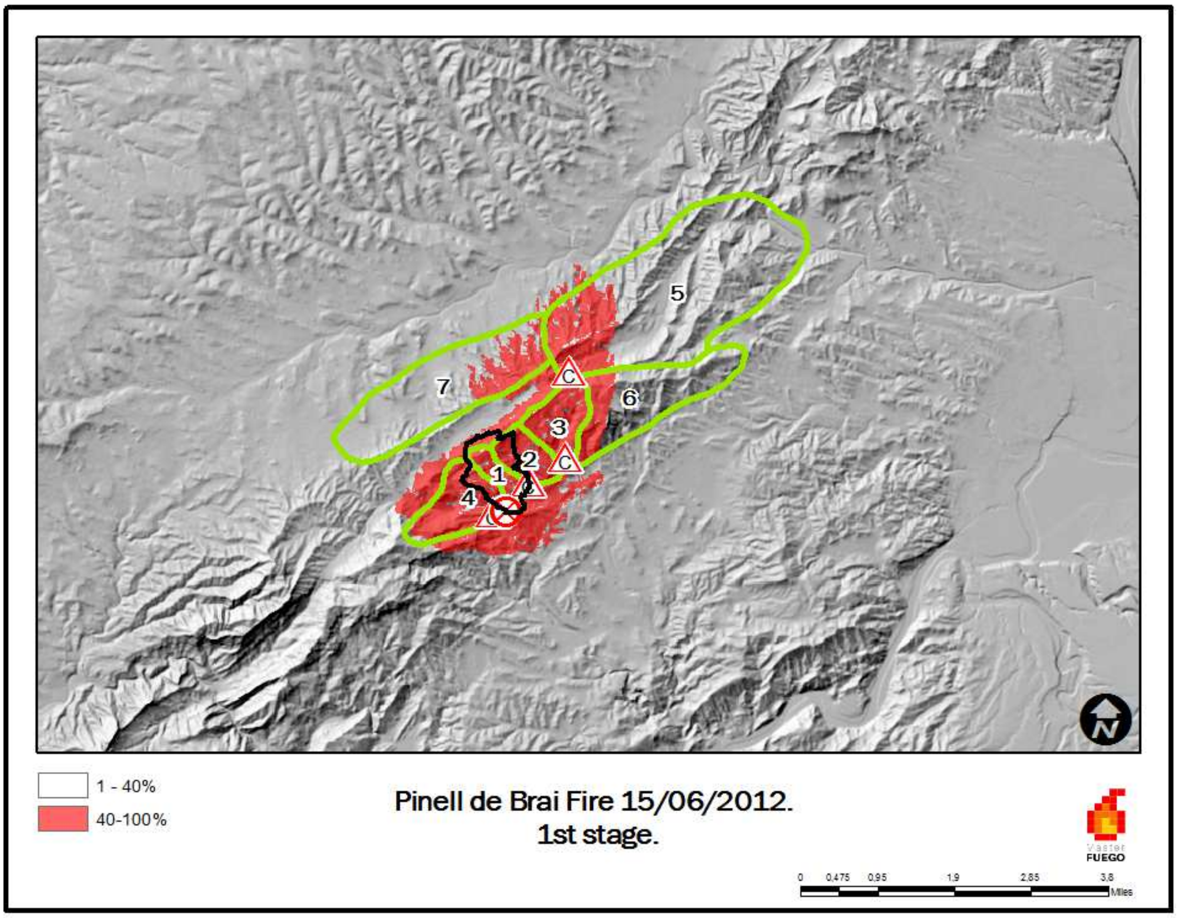

Figure 8 Pinell de Brai Fire 15/06/2012. Stage 3.

In the first stage, the affected fire potentials areas are number 4,1,2,3 and part of 5 and part of 6. It corroborates the predefined strategy, so the fire can spread to fire potential area 4, and cross at the other ridge in the southwest. The main spreading direction is on the right flank, due to southeast or south wind.

2nd Stage

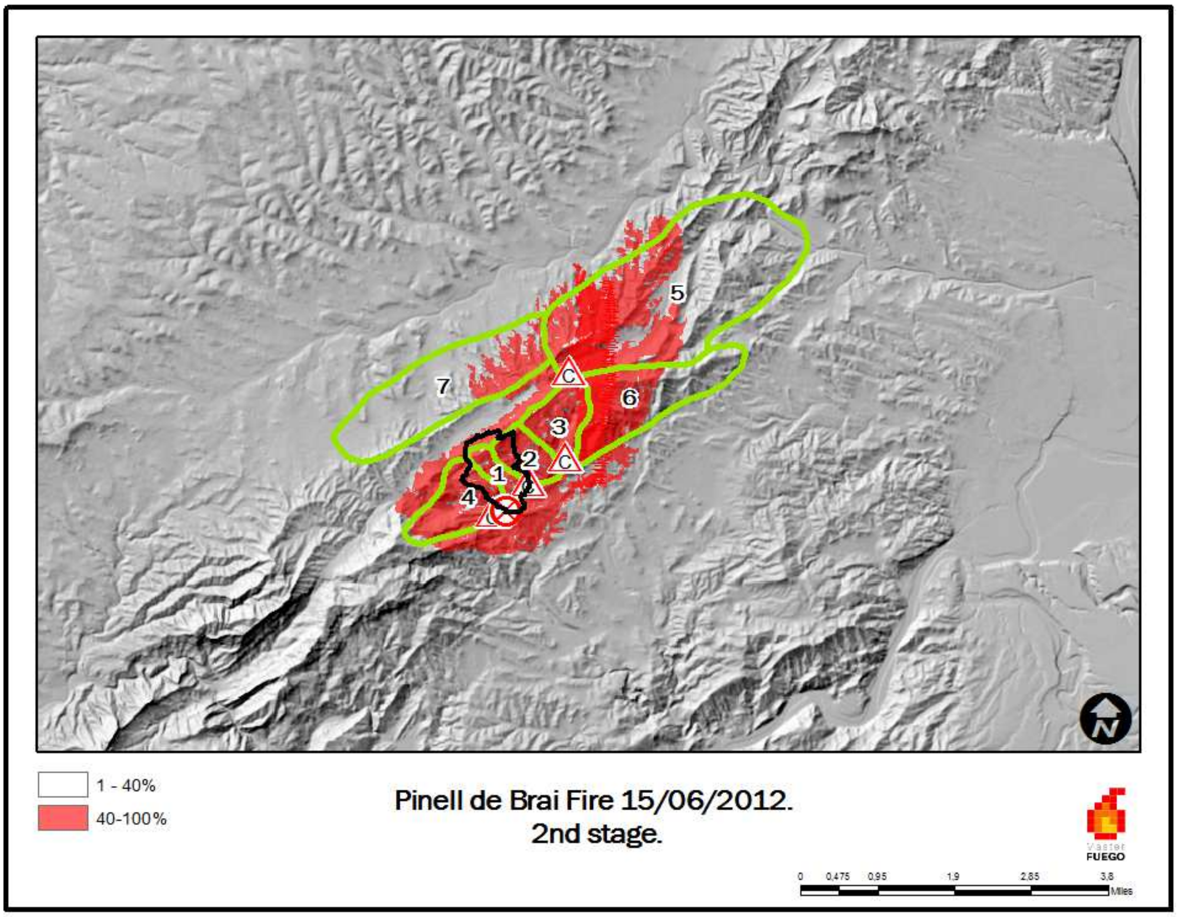

Figure 9 Pinell de Brai Fire 15/06/2012. Stage 2.

In the second stage the fire grows again in the right flank, due to southwest wind. It means the affected fire potential areas are 5 and 6.

3rd Stage

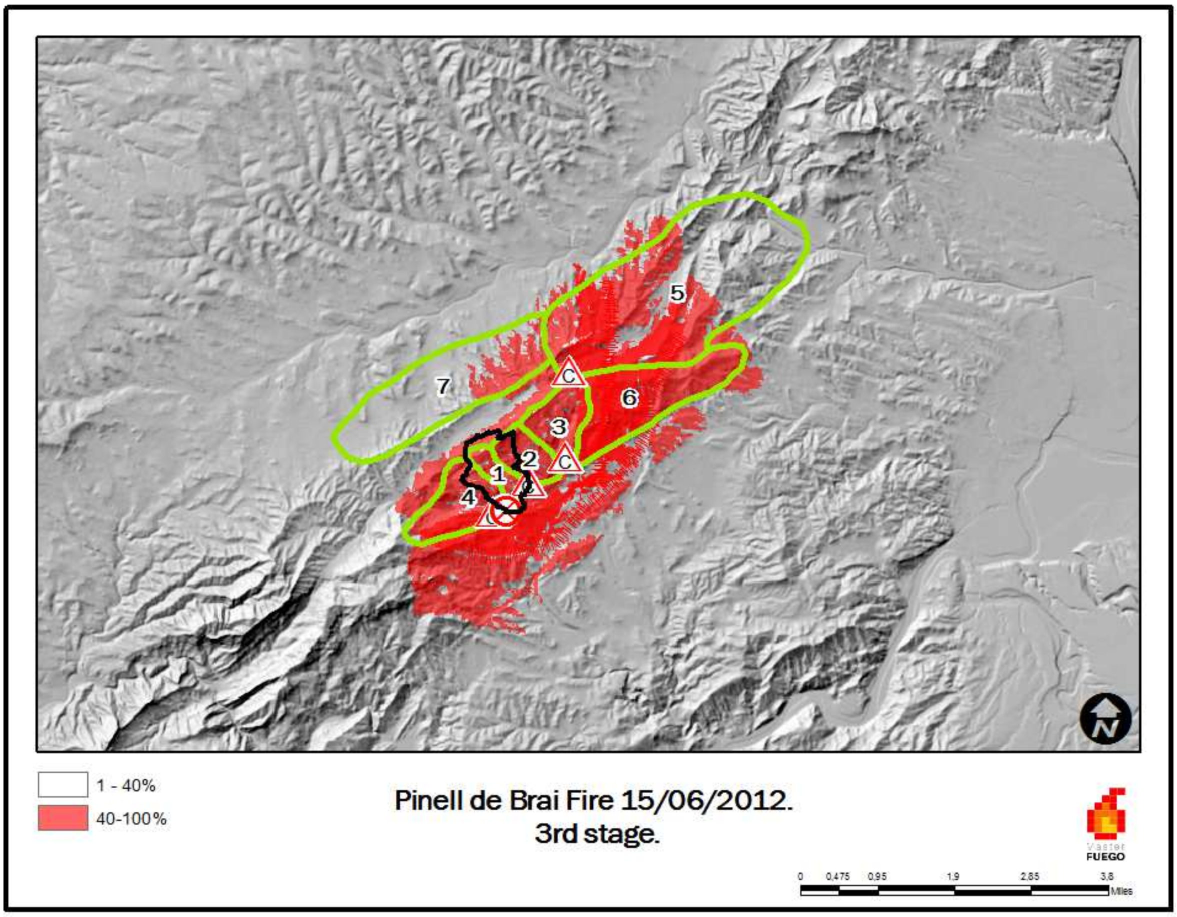

Figure 10 Pinell de Brai Fire 15/06/2012. Stage 3.

Without sea breeze and with downslope wind the rear part of the fire grows, slower than the other stages, so the wind velocity is slower.

Tactical simulations

Propagation mode

1st Stage

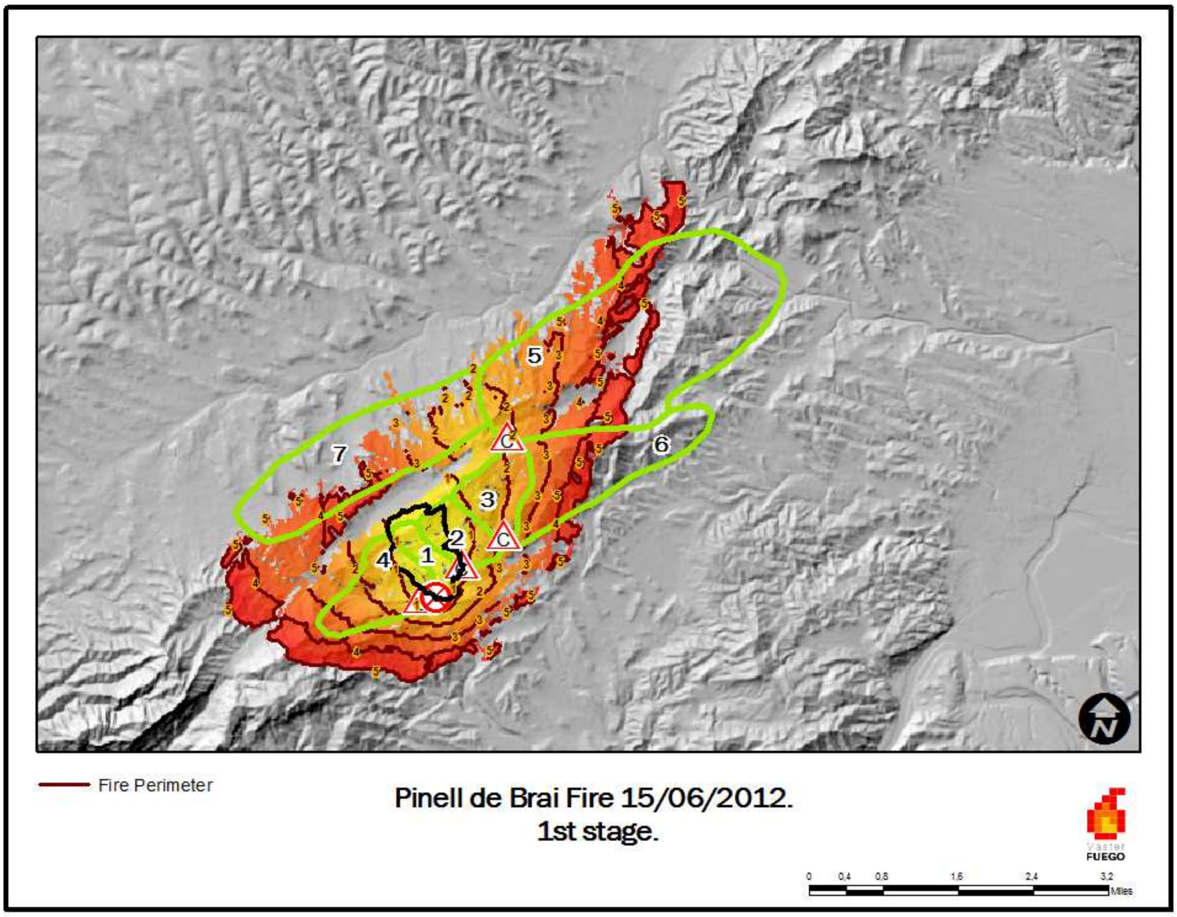

Figure 11 Pinell de Brai Fire 15/06/2012. Stage 1.

In tactical simulations we obtain the fire arrival time at the critical points. Therefore we can define the strategy, giving priorities to the different critical points and opportunities we have. In this figure we have about 1 hour before the afire arrive at critical points of fire potentials areas 4 and 2, and about 2 hours before it arrives at fire potentials areas 3 and 5. In this fire, it is important avoid that the fire arrive at fire potential area 5. It validates the strategy; the first priority was to contain the fire in the northeast ridge, to avoid the cross to fire potential area 4. In this simulation we can observe that the fire crosses to fire potential area 4 in 1 hour. The second priority was the critical point towards fire potential area 5, the right flank. Progressing along the right flank from the rear to the head, we will gain more time and we will have a larger spatial-temporal window (actuation window).

2nd Stage

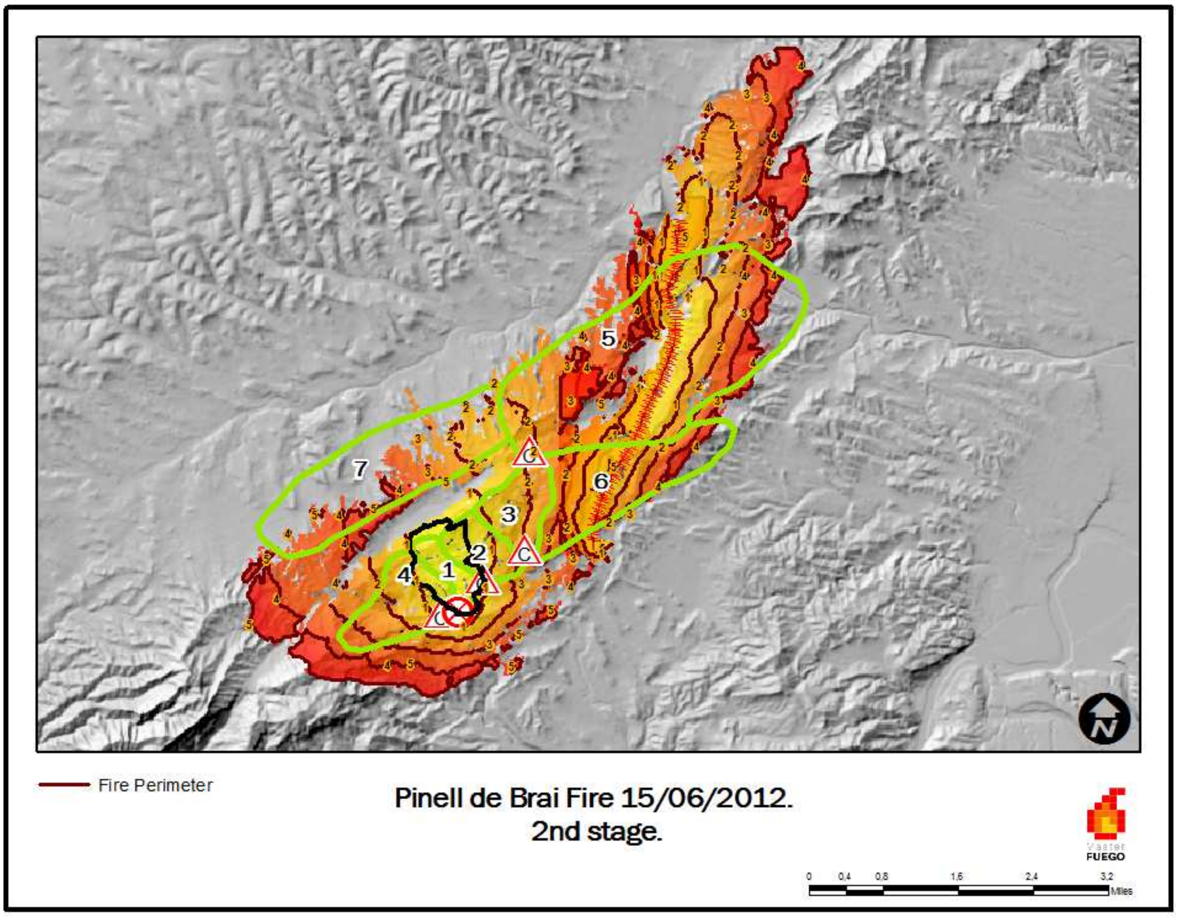

Figure 12 Pinell de Brai Fire 15/06/2012. Stage 2.

3rd Stage

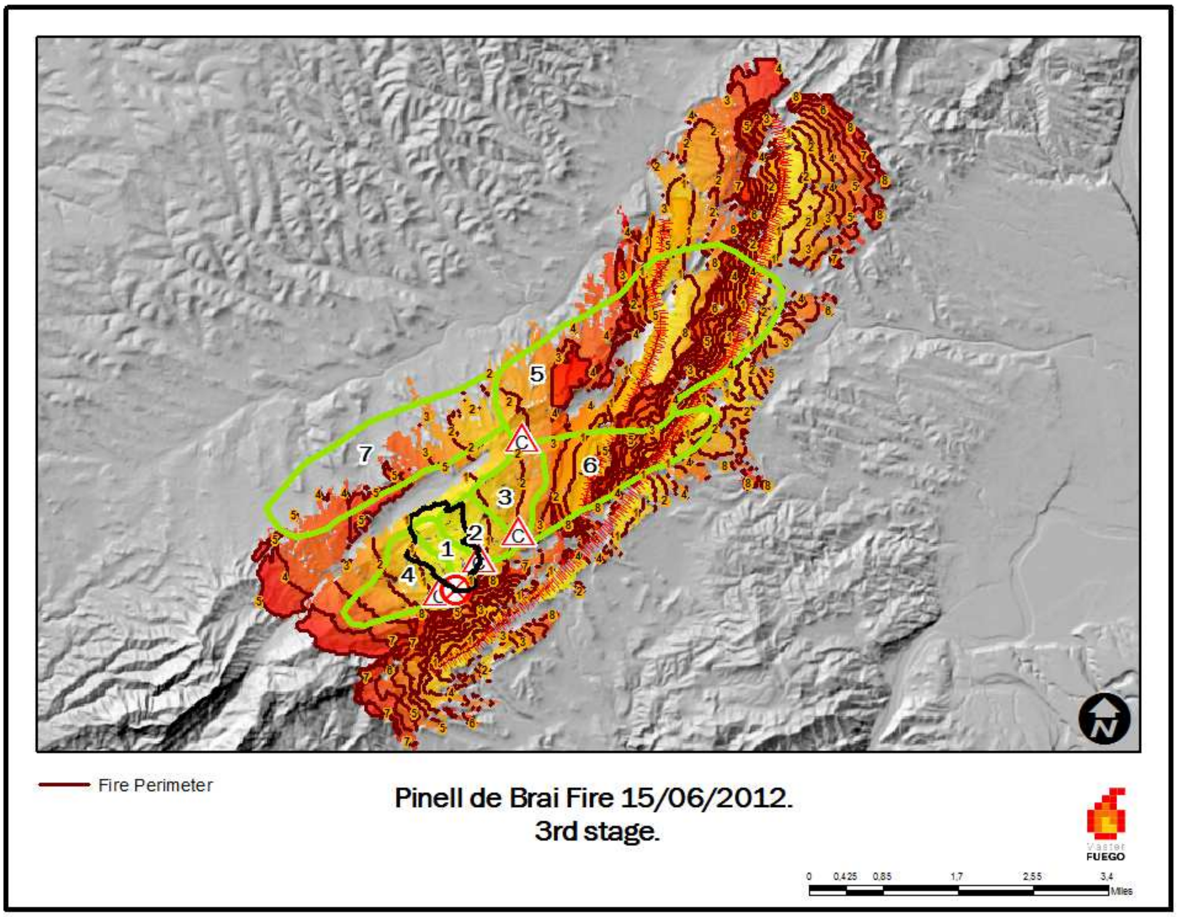

Figure 13 Pinell de Brai Fire 15/06/2012. Stage 3.

Evacuation Mode

1st Stage

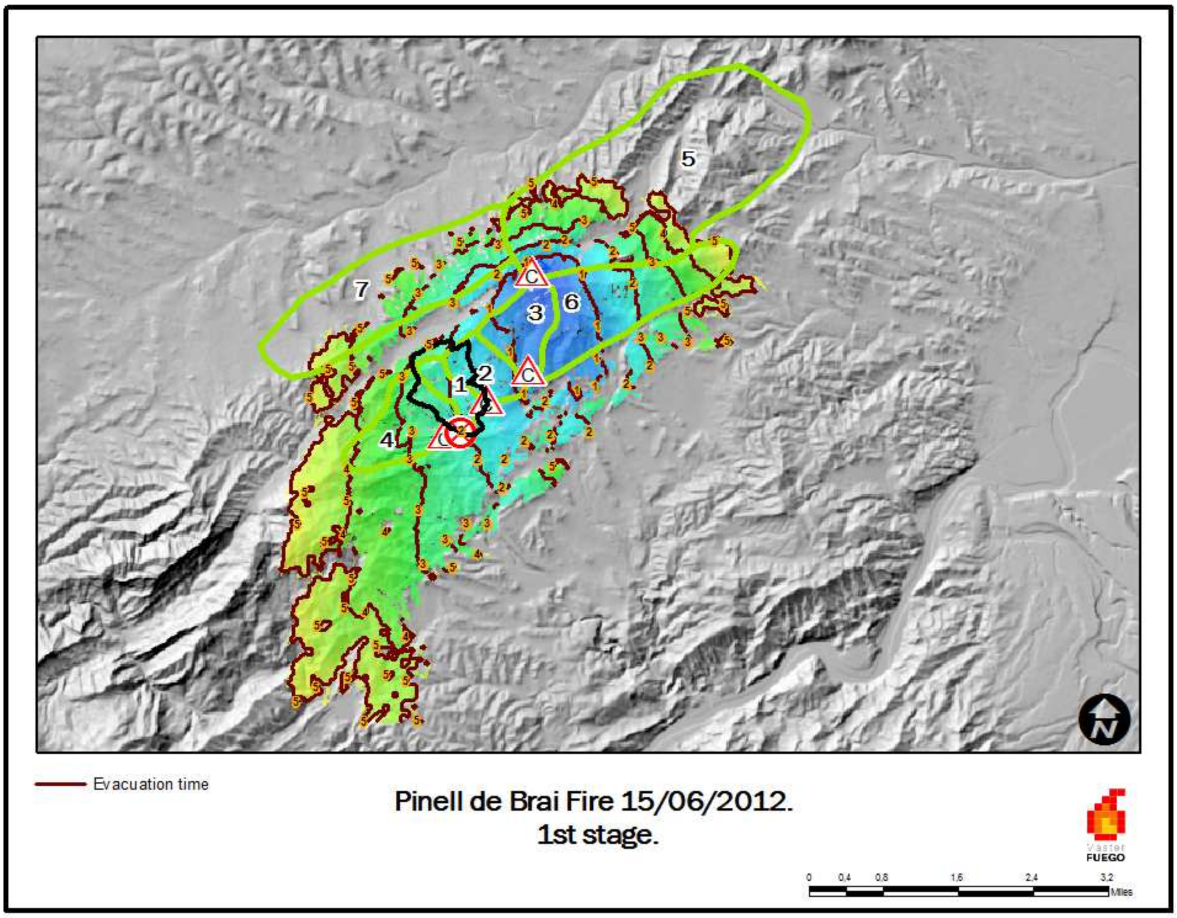

Figure 14 Pinell de Brai Fire 15/06/2012. Stage 1.

This simulation corroborates the arrival time to the critical point of potential 5 is 2 hours.

Mountain Fire 15/07/2013

It was located in San Jacinto Mountains, San Bernardino County, California, United States. It was a topographic fire with a weak W-NW wind at mid-day. The wind helped the fire to spread, doing the firsts runs to the top of the ridge, and probably throwing embers in the other part of it. Once in the other part of the ridge the fire followed a topographic pattern.

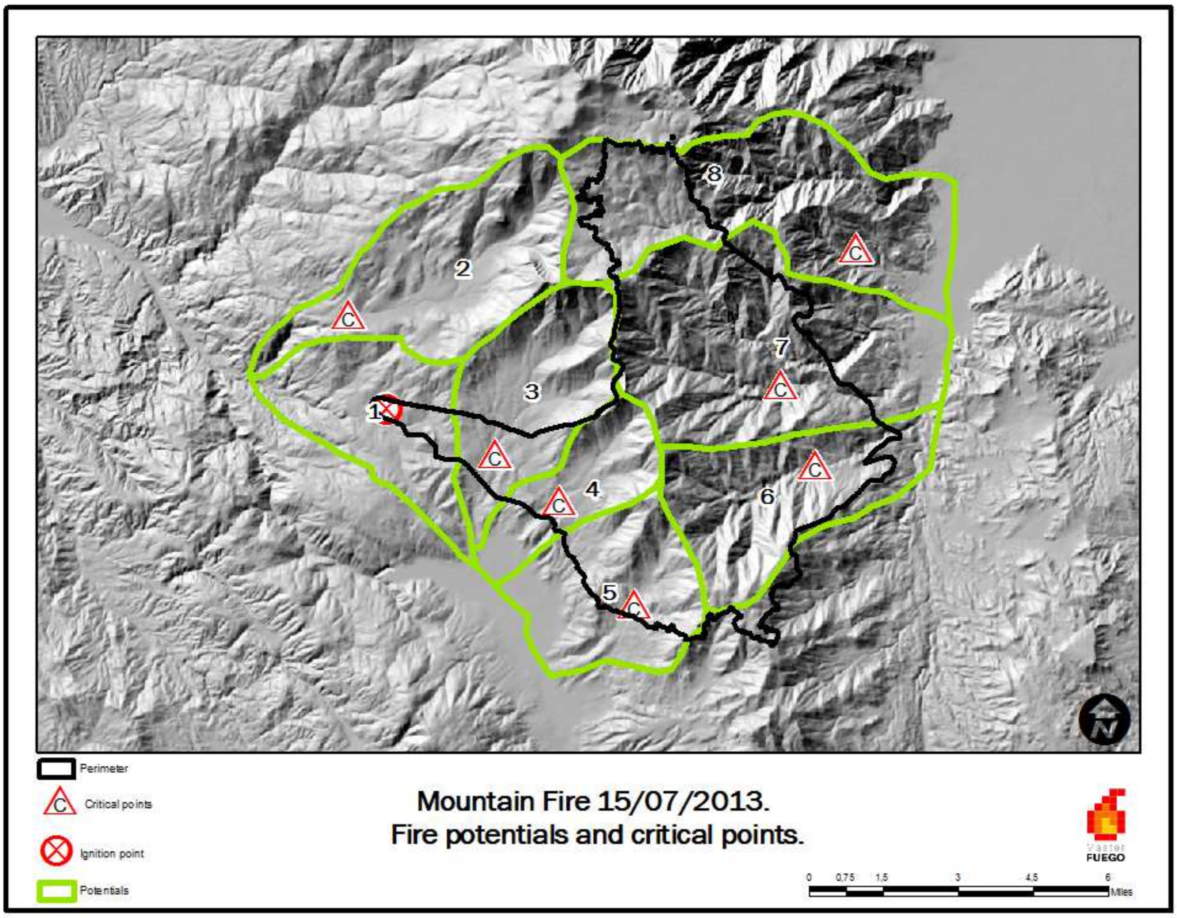

Figure 15 Mountain Fire 15/07/2013. Fire potentials and critical points.

The potentials sequence is the next:

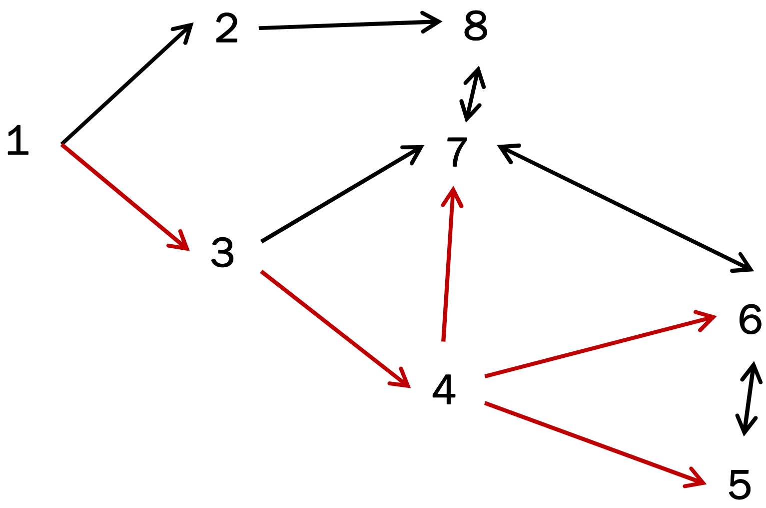

Figure 16 Potentials sequence Mountain Fire 15/07/2013.

This scheme (figure 16) shows a red arrow pointing the fire actually did burning fire potential area 1, 3, 4, 5, 6, 7 and 8. The first action was stop the pass of the fire to the potential 2 and consequently potential 8, then work to the right flank to avoid the pass to the other ridge, and finally work as independent spot fires in the other slope of the ridge to limit the burning surface of potentials 6, 7 and 8.

3 questions:

- **What does the fire want to do?** It wants to burn all the watersheds of the ridge, including the other side of it. If cross the valley it can burn the watersheds of there, but with head wind.
- **What can the fire really do?** Burn one watershed and flanking downhill to the ravine (critical point) and burn the other. It will be a constant in the fire, following a topographic pattern, doing runs upslope and burning watersheds. When the fire is at the top of the ridge (end of the run), it can throw hot spots in the watersheds of the other side of the ridge and they can do new runs upslope, and burn new watersheds.
- **What can we do to avoid this?** Attack fire from the cue to the head, reducing the potential of news runs.

In this fire the trigger/critical points are the ravines and the join of ravines. So the arrival of it in every ravine means the entrance of a new potential. Another trigger point is the arrival of the fire at the other ridge of another part of the valley.

In this fire our problem is the opening of the left flank, it will do runs to the top of the ridge and throw hot spots to the other part of it, these will become new fires which will burn other watersheds. So we have to try to avoid this runs to reduce the throwing of these hot spots.

In this fire we have 4 problems, so 4 priorities:

1. The left flank, which do runs to the top of the ridge.
2. The right flank cross the valley and enter ant the other ridge. If it cross, we we'll have two fires, so the problem will be reach.
3. Structures in potential 4.
4. The throwing of hot spots to the other side of the ridge.
5. The lighting of these hot spots, which will become new fires.

Strategy:

1. Flanking the left flank from the cue to the head so we will reduce the potential of new runs and consequently the throwing of hot spots at the other side of the ridge. Start flanking from the cue means that the potential 2 is out. With the advance of this flanking we will leave out the next potentials (3, 4, and 5).
2. Flanking the right flank, to avoid the crossing to the other part of the valley.
   We have an opportunity in the potential 4. There a flat area with structures and area no burnable and some trails, where it would be possible try to light a backfire, to defend the structures and stop the head of the fire, before it burns the potentials 4 and 5. If we can stop the head here the runs to the top of the ridge will be minor.
3. To reduce and limit the throwing of hot spots, with retardant droppings on the top of the ridge.
4. Put resources at the other side of the ridge, to attack new fires produced by hot spots. They will be topographic fires, so the resources will have to flank these, to reduce the potential of new runs.

This would be the initial strategy for the first 6 hours of the fire (1st stage). If the fire jumps to the other side of the ridge or cross the valley we will have to make a new strategy. We don't know the exact position of these new fires, so we only con make the simulation of the first stage. Once get the exact position of them we can make the next simulations.

To apply the methodology we have to define the stages from the weather of the day, they are the next:

Table 2 Stages resume.

Stage	Temperature (ºF)	Relative humidity (%)	Wind module (mi/h)	Wind direction (º)
1	90	20	13	290

In strategic simulations we use the propabilistic mode, as you know. To simulate with this mode we use the following inputs:

- Number of simulations: 100
- Variation of wind direction: 30º
- Variation of wind module: 10 mi/h
- Variation of fuel humidity: 3%

The limit is fixed in 60% of burned probability, so it means we guess the 60% of the simulations of the probabilistic mode affects determined potentials.

Strategic simulations

Probabilistic mode

1st Stage

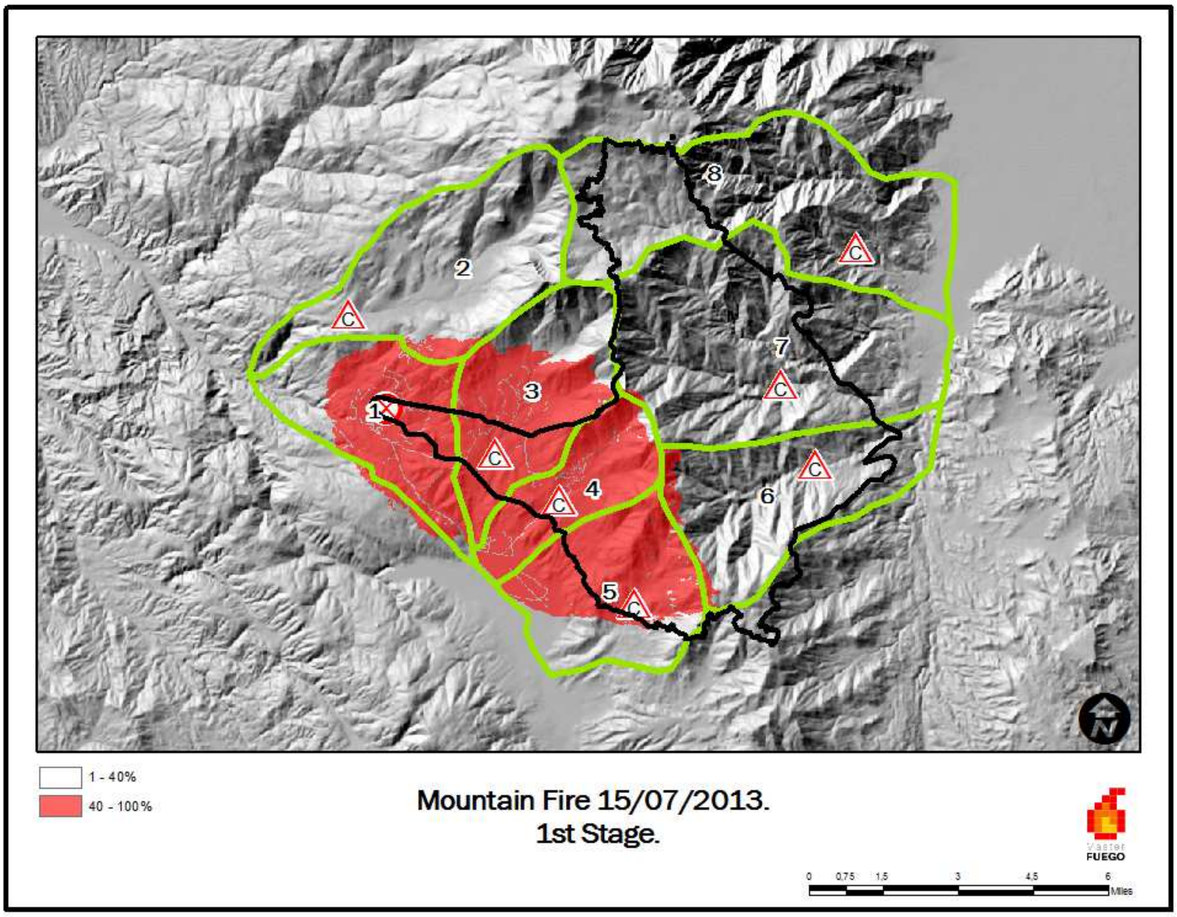

Figure 17 Mountain Fire 15/07/2013. Stage 1.

In the first stage the affected potentials are potential 1, 3, 4, and 5. In 6 hours the fire is on the top of the ridge, it means that possibly it is throwing spot fires at the other part of the ridge and starting new fires which will follow a topographic pattern spreading upslope and burning watersheds.

Tactical simulations

Propagation Mode

1st Stage

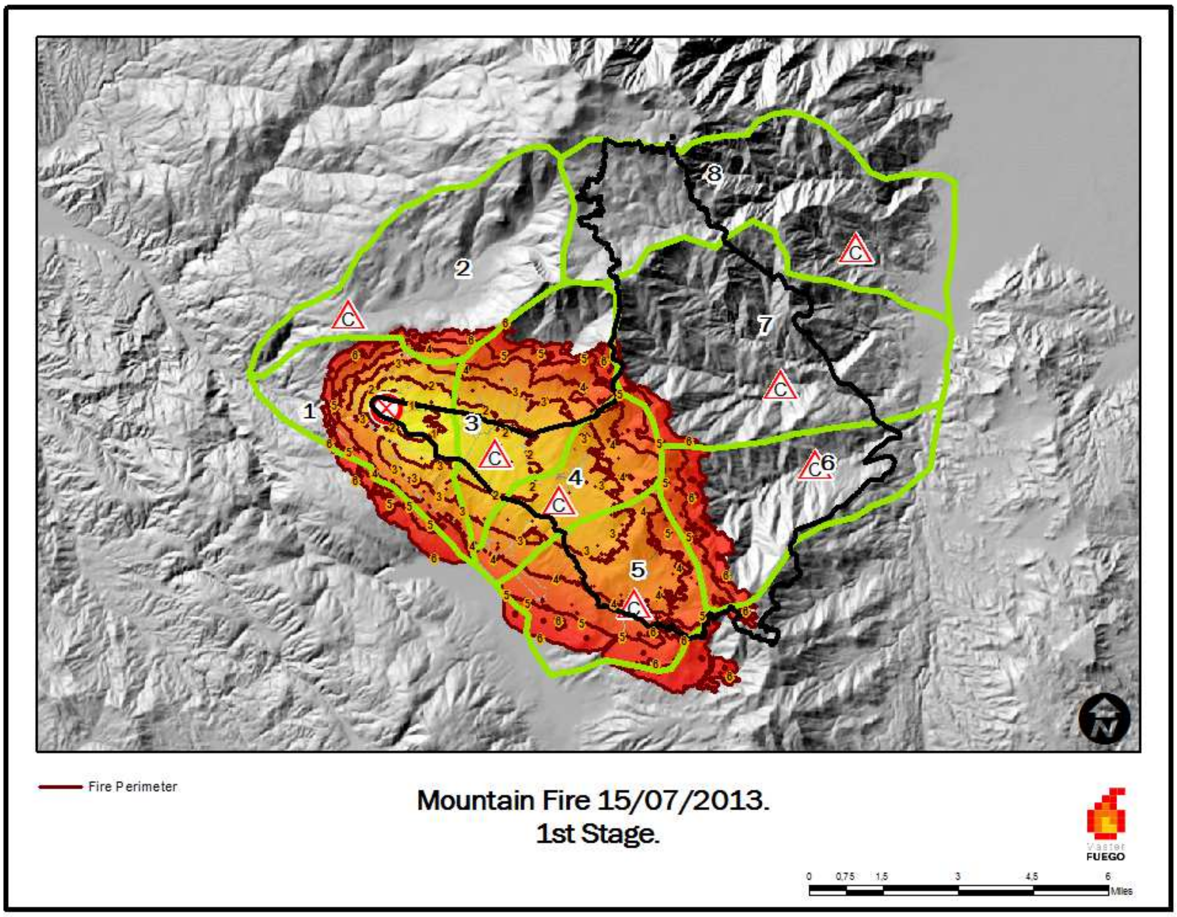

Figure 18 Mountain Fire 15/07/2013. Stage 1.

This tactical simulations tells us the arrival time of the fire in the critical points of potential 3, 4 and 5. For the first critical point (potential 3) the arrival time is between 1 and 2 hours, for the next critical point (potential 4) it is between 2 and 3 hours and for the last critical point (potential 5) it is 4-5 hours. This simulation also shows that in 6 hours the fire is on the top of the ridge.

Evacuation Mode

1st Stage

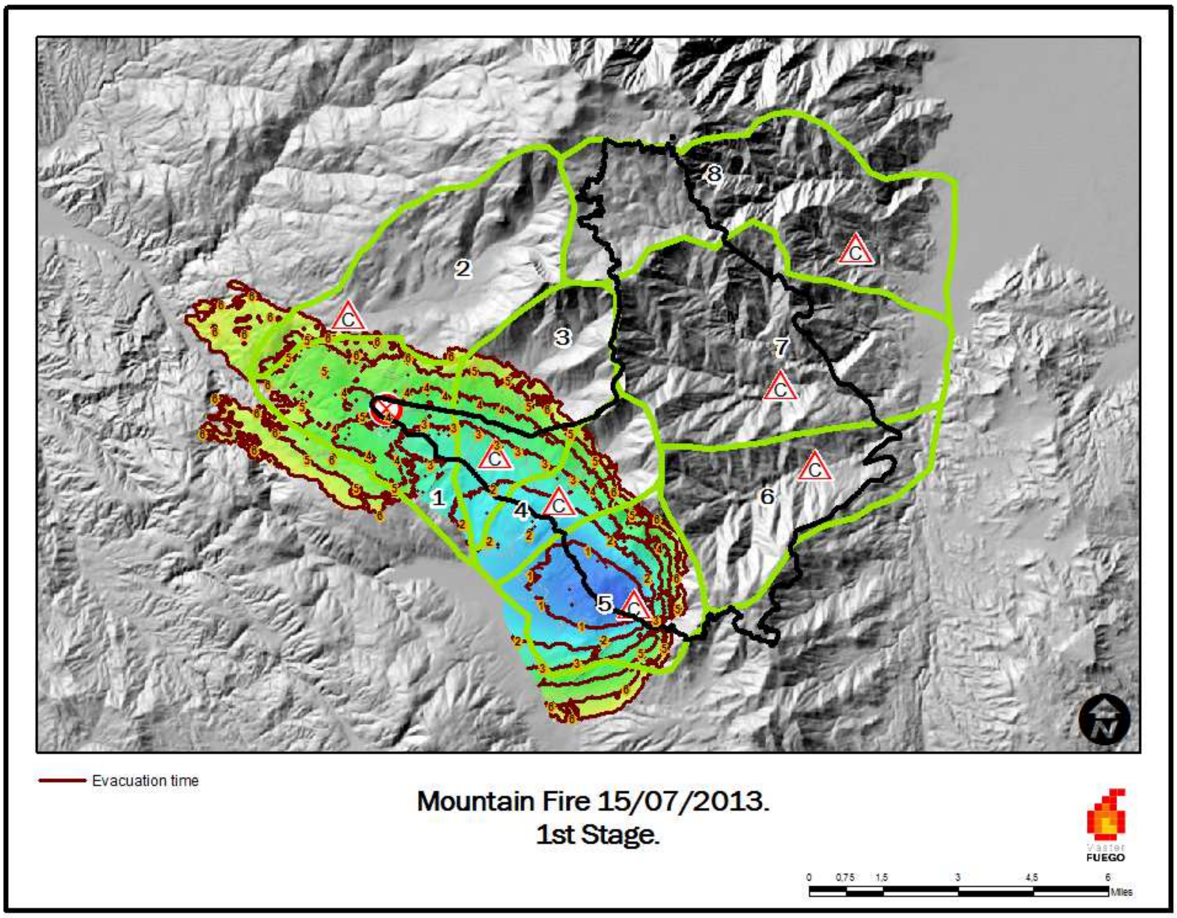

Figure 19 Mountain Fire 15/07/2013. Stage 1

It also shows the arrival time of the fire at the critical points but using the evacuation mode. It tells us the fire will be in 4-5 hours at the critical point of the potential 5, so it corroborates the previous simulation, with the propagation mode.

Conclusions

Wildfires exceed the suppression capability for intensity, velocity and number of assets to be protected. The fuel management can modify the fire intensity, obtaining more resistant fire fuel structures. Wildfire analysis, CPSL and strategic analysis are tools to anticipate the wildland fire, increasing the velocity of decisions and therefore deciding in advance of the fire. Wildfire Analyst™ is a tool to help us in the decision process while the fire is spreading, as it gets real time data from fast simulations adjusted with real control points obtained directly from the fire.

The conclusions, after this work, are next:

- The developed operational methodology provides step by step the process to get determined outputs to support the strategic and tactical decisions, giving answers to the uncertainty created during wildfires. It is a tool to support strategic and tactical decisions, it is not a tool to take them, and so it has to help the WFA in his work. The software Wildfire Analyst™ allows calibrates simulations and adjust them quickly and simply, so we can do it in every stage. The simulations will be more reliable and consequently it is adequate to use in real time in wildfire management. To apply this methodology a deep knowledge of fuels and the fire types (Castellnou et al. 2011) is mandatory. The simulator contributes doing the process and providing data and robustness. However, it has to be a WFAN who supervises the process and the inputs, doing a quality control. The methodology shows, in one hand the importance of the exact situation of the fire location the precise fuels definition and its conditions of the day. On the other hand the relative importance of having a complete and detailed weather files. The WFAN knowledge of the area is essential, knowing the principal direction of the fire spread and the wind interaction in the geomorphology we can apply the Methodology. So with less detailed inputs we get faster and simpler simulations, therefore we can take faster decisions.

- To manage a LWF we have to develop a sequence of actions and why those (strategy) to decide which fire potentials will burn and which will not burn following a determined criteria. These actions will be executed in a determined place and a determined time (tactics) by wildland firefighters using a determined tool or technique or combination of them (maneuvers) to suppress, contain o hold the fire. It is important establish a strategy and some tactics, for this way we will have a clear and defined idea to manage the fires and we can decide in advance of the fire, knowing what we do and where and when put resources from the beginning. To take strategic and tactical decisions is needed a general vision of the fire, not focusing in flames, it is important identify the critical points, the fire potentials and the chances the fire offers us. Doing all of this we will be proactive and we will can decide in advance of the fire, anticipating it. These concepts evolve, clarify and contrast the definitions explained in classic wildfire manuals (Teie, 1994).
- The methodology was tested in Catalonia and the Southern California, as the share a similar fire regime of fast and intense wildfires In areas like these, it is important take decisions in the very first moments, and this is when this methodology fits. It is designed in a technical and objective way following an expert criteria assessment, so it can be extrapolated in other territories, as is pointed in this article.
- To be able useful in wildfire operations, analysis tools have to give quick answers. Wildfire Analyst™ provides the innovative Adjust Mode that allows an extension of the Rothermel's model as it calibrates and makes adjustments on the fly with field control points, sound and reliable fire predictions in real time. We can calibrate and adjust the simulations several times during the fire is spreading obtaining more reliable outputs that will be used to support most fitted decisions. Wildfire Analyst™ is an evolution of simulators like Farsite (Finney, 1998) and its associated training (S-495, NWCG) not adequate in real time operations due to its long processing time. It fills a gap between this and the long term simulation analysis developed in WFDSS to support large scale incidents (ref a WFDSS).
- The new technologies applied in wildland fire management provide to wildfire staff tools to do their work more efficient and consequently safer. It is important that there should be an interaction between the staff who works in wildfire suppression and people who develop technology adapted for them, these increasing technologies have to be guided for the real necessities of wildfire issues, for this way they can be a useful tools.

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